NASA-CR-54743

DEVELOPMENT OF ELECTRICAL SWITCHGEAR FOR SPACE NUCLEAR ELECTRICAL SYSTEMS

QUARTERLY PROGRESS REPORT NO. 3

For Period: June 4, 1965 Thru Sept. 4, 1965

EDITED BY A. H. POWELL

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3- 6467 - PHASE I

SPACE POWER AND PROPULSION SECTION

MISSILE AND SPACE DIVISION

GENERAL ELECTRIC

CINCINNATI, OHIO 45215

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D.C.
Attention: AFSS-A

DEVELOPMENT OF ELECTRICAL SWITCHGEAR FOR SPACE NUCLEAR ELECTRICAL SYSTEMS

Quarterly Progress Report No. 3

Covering the Period
June 4, 1965 thru September 4, 1965

Edited by:

A. H. Powell
Program Manager

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-6467

Technical Management
NASA---Lewis Research Center
E. A. Koutnik

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

FOREWORD

This report describes work which has been completed during the period from June 4 to September 4, 1965, the present status, and the future plans for the effort being performed by the General Electric Company under Contract NAS 3-6467 from the National Aeronautics and Space Administration. The objective, as outlined in the contract, is to develop and design ground prototype AC circuit breakers and DC engine contactors, suitable for, and tested under, expected launch and space requirements. The Breakers will be rated 1000 volts, 600 amperes, 2000 cps, while the DC Contactors will have a rating of 10,000 volts, 10 amperes.

Management of the program for General Electric Company has been assigned to A. H. Powell, Manager - Electrical Systems, Space Power & Propulsion Section. Consulting Engineer is R. N. Edwards, SPPS. Project Engineer is E. F. Travis of the Research and Development Center in Schenectady. Contributors to this report, in addition to Messers. Powell and Travis, include G. Gati of SPPS and G. W. Kessler of R & DC.

Mr. E. A. Koutnik of the National Aeronautics and Space Administration is the Technical Manager for this contract.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

This program is a continuation of the Electrical Switchgear development and investigation work which was completed under Contract NAS 3-2546 with the successful interruption of over 20 amperes at 10,000 volts DC, and over 1800 amperes at 1200 volts, 2000 cycles per second.

The goals for this program, Contract NAS 3-6467, were established so as to provide detail background information and knowledge on which final flight hardware for planned Nuclear Space Power Systems of 1 to 4 megawatts capacity could be built. The breaker is being developed to have a rating of 600 amperes (1000 to 3000 cps) and 1000 volts, and the contactor to handle 10 amperes at 10,000 volts DC.

Development effort on this contract will result in building and testing ground prototype Breakers and Contactors which can withstand launch environment (mechanical) conditions, as well as expected space conditions including low pressure, high temperature, and radiation. The devices are also to be able to successfully interrupt short circuits of twice normal current ratings.

Program Management is centered in the Space Power and Propulsion Section of the General Electric Company in Evendale. The major development work is being done at the Research and Development Center (formerly the Advanced Technology Laboratory) in Schenectady, with technical and test assistance from other Laboratories and Departments of the Company. The long time endurance tests will be made at SPPS, most mechanical and all interruption tests in Schenectady, and the acoustic and acceleration tests in the RSD Mechanical Testing Laboratory in Philadelphia.

II. SUMMARY

During the third quarterly period of this program, all details for making the sample breakers and contactors were completed, most of the required raw material was obtained, and plans for fabrication and assembly were initiated. An overall review of the program was made at NASA-Lewis in Cleveland on August 19 with representatives of NASA, General Electric Company's SPPS and the Advanced Technology Laboratory present.

This report will tell of further detail investigation work in connection with parts of both the Vacuum Interrupters and the Actuators. Proposed construction and assembly methods were checked out, and improved latch and trip mechanisms were created and included in the final design. The designs have now been frozen and all detail and assembly drawings have been issued. A sketch of the complete breaker is given in Figure 1.

While the raw material has been ordered, none has been released for fabrication pending determination of the most favorable processor. This review is now underway. Test specifications are also being prepared, and high vacuum oven equipment for the first tests (heat run) has started to be assembled. Schedules have been considered in detail, and the PERT diagram which is included in Section VII provides expected milestone dates. Delays in fabrication, and some modifications in the order of testing now appear to result in some extension of the final program completion.

During the next quarterly period, the first Breaker (vacuum interrupter and actuator) will be fabricated, assembled, and preliminary testing started. Fabrication of parts for the other samples will be in process.

III. VACUUM INTERRUPTER

The vacuum interrupter includes the sealed capsule along with the related parts needed to conduct current in and out of the unit, means for removing the heat generated, and insulation between the line parts and grounded supports. This section of the report will tell of further detail design work and describe the final interrupter design.

A. Thermal Calculations and Contact Heating

The design of the radiator system for the AC Circuit Breaker described briefly in the Second Quarterly Report has been completed. In the final arrangement all of the fins radiate to the enclosing shell which is isolated from the electrical system and is bolted to the heat sink bulkhead.

The temperature of the contacts, radiator fins, and outer shell has been calculated for this latest design and the values are indicated in Figure 2 , an outline drawing of the heat transfer system. The temperature of the contacts a few mils back from the surface will be approximately 820°C, as shown in Figure 2 . The local temperatures at the actual pinpoints of contact may be considerably higher, as described in the theoretical review in Section III-B-1 of the Second Quarterly Report. Note from Figure 2 that both of the contacts calculate to be at nearly the same temperature even though the upper contact "heat radiator" is smaller than the bottom one. This results from the lower temperature of the outer shell or "radiation sink" to which the top contact radiates.

A further investigation of the effects of high temperature on the contact resistance as outlined in the Second Quarterly Report has been completed. This detail activity was planned to supplement the theoretical information and review of contact behavior at high current and high temperature.

The materials test capsule used in Phase I was reassembled with the contacts used during the interruption tests. These contacts were used because the surfaces were rough due to the current interruptions, and were representative of breaker contacts in service.

The radiant cylindrical contact heater was removed from the capsule and the flanges supporting this heater were used to bring out electrical connections from the contact tips for the direct measurement of contact voltage drop.

Thermocouples were installed at the locations indicated in Table I and the unit was placed in the same oven used in the previous tests. After a preliminary vacuum bake-out at 1×10^{-6} Torr pressure and $250^{o}F$ temperature, the contacts were sparked at 15 KV and 60 ma to clean the surfaces. During this operation the pressure in the capsule increased to 5×10^{-6} Torr.

Both the current through the contacts and the oven temperature were then increased slowly. The contacts were permitted to reach an equilibrium temperature after each incremental increase in contact current. The temperature, voltage, and current measured during the test are included in Table I.

The final resistance of the contacts, measured with direct current flowing at room temperature and before the switch was moved, was 0.0225 milliohms. This is considerably below the initial resistance, or the resistance measured after the switch was opened and closed again at which time the value was 0.141 milliohms. Apparently asperity softening has taken place at contact temperatures between 800 and $1200^{o}F$. The curve in Figure 3 shows the relationship of the measured contact resistance to temperature and indicates it is flat in this region.

B. Capsule Heat Conductor Material

1. Selection

A detailed review of available materials was made in selecting the proper one for the radiation fins and outer shell of the AC breaker (the highest temperature unit). The following tabulation lists the important properties of some of the candidates:

Material	Thermal Conductivity (Watts/cm^2/^{o}C) at 800^{o}C	Density (gm/cu cm)	Electrical Resistivity (ohm-cm) at 800^{o}K	Vapor Pressure (Torr) at 800^{o}K	Yield Strength (psi x 10^3) at 800^{o}K	Machinability (GE Standards)	Merit Figure for Thermal Conductivity per lb.	% Linear Thermal Expansion at 800^{o}K	% Linear Thermal Expansion at 1000^{o}K
Copper	3.54	8.9	4.8	10^{-8}	----	.6	.397	.95	1.4
Copper Zirconium	3.3	8.8	6.1	10^{-8}	34	.6	.375	.96	1.6
CUBE-ALLOY[1]	2	8.7	5.5	---	42	.6	----	1.03	1.3
Tungsten	1.25	19.3	18	10^{-8}	---	.1	.065	.20	.32
Molybdenum	1.21	10.24	17	10^{-8}	30	.35	.118	.24	.4
Beryllium	.92	1.85	25	10-^{8}	---	.8	.5	.88	1.3
Nickel 200	.52	8.87	35	10^{-8}	13	2.0	.059	.85	1.1
Stainless Steel 347	.29	7.905	110	---	19	.40	.037	1.0	1.4
Kovar[2]	.16	8.3	---	10^{-8}	---	.65	.019	.34	.61
Alumina	.11	3.71	$3x10^{17}$	10^{-7}	26	---	.030	.40	.57

[1]Not available in required forms
[2]Kovar FE-Nl-Co Alloy similar to Rodar

The first choice material was copper since it has excellent thermal and electrical conductivity. Copper reportedly loses its strength at high temperatures, but R.A. Wilkins and E.S. Bunn, in their book titled "Copper and Copper Base Alloys", state that copper has a tensile strength of 4,000 psi at 700°C. This would be sufficient strength for the outer shell which have a maximum calculated temperature of 605°C, and probably for the radiator fins with a maximum calculated temperatures of 660°C. Figure 2 shows the results of the temperature study just completed and the location of these points. However, the temperature of the flanges on the vacuum capsule were calculated to be approximately 700°C, which would make the use of copper marginal.

CUBE-ALLOY, a dispersion hardened high conductivity copper base material, was investigated for the vacuum capsule flanges because of its relatively high strength at high temperature. However, this promising material was found to be available only in wire up to 1/2" diameter rod, and thus not suitable for the radiators.

A third material with good thermal and electrical properties is copper-zirconium. This material retains appreciable strength even at the expected switch temperatures. The strength of this material is obtained by alloying a small percentage of zirconium with copper into a precipitation hardened material. Over long time periods at high temperatures it is reported that the zirconium will go back into solution and be no stronger than copper. Information from American Metal Climax, Inc. maker of the material known as AMZIRC indicates, however, that sufficient zirconium will be left in the grain boundaries to accomplish the strengthening function. While specific data were not available at 750°F, the following typical information has been made available.

At $600^{\circ}C$ a 17% cold worked specimen took 100,000 hours to creep 1% at 1,000 psi. At $650^{\circ}C$ the data for various amounts of cold work indicated:

Cold Work %	Ultimate Tensile psi	.1% Yield psi	Elongation %
None	8,500	4,700	8
5	10,500	8,500	7
20	15,000	13,000	4
40	18,700	16,500	4

Based on these data, the copper-zirconium has been selected for the flanges of the vacuum capsule, and copper for the interrupter outer shell. Copper will also be used for the upper radiation fin, but copper-zirconium will be required for the lower fin since it supports the vacuum capsule.

2. Brazed Contact Assembly Samples

Several samples of brazed vacuum capsule contact assemblies were made and tested at $700^{\circ}C$ to obtain basic data for the final design. The configuration of the samples is shown in Figure 4 . The sample assembly is representative of the contact arrangement in the vacuum capsule. The brazing of the molybdenum, rodar, and copper was completed in a single brazing operation. A nickel-gold braze material, melting at about $950^{\circ}C$, was used for each braze joint.

Two samples (#2 and #3 of similar design) were subjected to three temperature cycles from room temperature to $700^{\circ}C$ and back to room temperature at the Research and Development Center in Schenectady. Sample #2 was heated in the atmosphere while sample #3 was heated in hydrogen. Each sample was subjected to a stress test in an effort to break the braze joint between the copper and molybdenum. Forces of 1,200 lbs were used with no apparent effect on the brazed joint.

The brazed joint between the fernico and molybdenum of sample #2 and the brazed joint between the rodar and molybdenum of sample #3 were checked for vacuum leaks before and after temperature cycling. The leak tests were made at a vacuum level of 10^{-6} Torr. A leak was not detected in any of the tests.

Another sample (#4) was heated in the hydrogen furnace with a weight of 50 lbs. attached to the molybdenum contact in an effort to break the joint while at $700^{\circ}C$. Again, the braze joint was not affected. The test was repeated with a 72 lb. weight, the maximum that could be put in the furance. The results were the same as with the 50 lb. weight.

From these tests, it was concluded that the brazing procedure is satisfactory for this application but, as an additional check, still another sample (#1) was delivered to Space Power & Propulsion Section in Evendale for test in the low voltage electron beam vacuum chamber. The sample was mounted on ceramic supports, surrounded by tantalum foil shields to reduce heat transfer. The shields, arranged as shown in Figure 5 , consisted of two layers under the sample, three on the side (all separations were 1/16"), and a single layer above the sample for two of the tests.

The sample was heated by directing a wide electron beam on the molybdenum contact. Heating current varied from 19 to 25 ma and the chamber pressure was 5×10^{-5} Torr. Five chromel-alumel thermocouples were mounted as shown in the sketch, Figure 5 , and three runs were made with the results indicated in the table included with the sketch. A plot of the temperature of the molybdenum contact during the first run with a shield is shown in Figure 6.

The heat flow and temperature rise obtained with this test closely simulated the expected vacuum capsule performance, and further substantiated the R & DC conclusion that the braze and general configuration would be satisfactory.

Any breaking of the joint would have been reflected in a definite reduction in heat flow. This did not occur, indicating the joint was secure and reliable.

C. Bellows Design

After extensive investigation of possible bellows designs and manufacturers, a sample welded bellows was obtained from the Metal Bellows Co. This sample was made up of 0.003" thick rodar convolutions and 0.020" thick rodar end pieces. From the experience gained in welding the sample bellows the Metal Bellows Co. confirmed they could furnish bellows satisfactory for this application. Based on a minimum life of 500 operations at a temperature of approximately 1300°F, the final design will consist of 7 convolutions of 0.003" thick rodar, with 0.020" thick end flanges. The following are the design specifications:

Spring rate	15 lbs/in.
Compressed height	0.12"
Stroke	0.250"
O.D.	2.75"
I.D.	2.00"

D. Interrupter Design Details

1. Vacuum Capsule

A single basic vacuum capsule has been designed for use in both the AC Circuit Breaker and DC Engine Contactor. Figure 7 is a sketch of the vacuum capsule.

The vacuum envelope consists of end bells of rodar, a rodar bellows, the alumina insulation with rodar spinnings brazed to the insulation. The rodar spinnings permit welding to the bellows and rodar end bell. A molybdenum vapor shield to protect the alumina insulation during arc interruption is riveted to the rodar spinning in the center of the insulation assembly. The molybdenum contacts are brazed to the rodar end bells and amzirc (copper-zirconium) flanges.

The amzirc flanges are designed for attaching either heat radiating fins for the AC breaker, part 8, in Figure 8 , or the vacuum capsule support for the DC contactor, part 6, in Figure 9 . In both of these figures the capsule is part 3. The heat radiation fins in the AC breaker are attached to the capsule flange by a temperature (heat) shrink process. This will provide a good thermal path between the contacts and the radiators.

2. Current Conductors and Terminals

The two external connections or terminals for both the AC breaker, part 9, Figure 8 and for the DC contactor, part 7, of Figure 9 are in line, one above the other, on the same side of the vacuum interrupter assembly. The top terminal on each switchgear device is threaded into a copper ring, part 10, Figure 8, and part 8, of Figure 9 . A flexible copper diaphragm, connected to the movable contact in each device, is brazed to the copper ring. The bottom terminal on the AC breaker is threaded into the lower heat radiation fin connected to the fixed bottom contact. In the DC contactor the bottom terminal threads into the ring supporting the vacuum capsule attached to bottom contact flange.

The flexible copper diaphragms in each device are of the same configuration except for the thickness of the material. The diaphragm for the AC breaker is .016" thick and the DC contactor diaphragm is .010" thick. Figure 10 is a sketch of the diaphragms.

A .010" thick copper diaphragm has been successfully vibration tested in a test fixture intended to simulate the extended locked position of launch. One resonant frequency was found at 535 cps and no damage resulted from the 5 minute dwell at 9.5 "g" at this frequency.

This same diaphragm was operated 3000 times through the full 1/4" stroke representative of close-open operation.

3. Insulation

The three major areas requiring electrical insulation are:

1) Vacuum capsule - between the end pieces.

2) 1000 volt AC vacuum interrupter - vacuum capsule and ground.

3) 10,000 volt DC vacuum interrupter - vacuum capsule and ground.

The devices are to be operated in a gas at the heat sink temperature of $1000^{\circ}F$ during the interruption tests, as well as in high vacuum during the heat run and endurance test.

The vacuum capsule being used in both of the vacuum interrupters requires insulation to withstand the high potential test of the 10,000 volt DC vacuum interrupter while at temperature and in a vacuum.

The insulation material that has been selected for all three areas is high density pure alumina ($al_2 O_3$). This material was first selected for the vacuum capsule because it is compatible with the rodar used for the end bells, and is suitable for furnace brazing. The high resistance of alumina (10^8 ohm cm at $700^{\circ}C$) also makes it suitable for the insulation of the vacuum interrupters. Further, the experience gained during Phase I with the alumina furnished by the McDanel Refractory Porceline Co., showed the material to have the required physical properties for all three insulating duties.

The specification used in designing the insulation for the vacuum capsule (and the 10,000 volt DC vacuum interrupter) required a surface creepage of 1 inch and a gap of 1/2 inch through the gas to be used during the interruption test. To meet these criteria it was necessary to design the insulation in the 10 KV device to completely cover the inside of the metal enclosing shell, part 14, Figure 9 . Also to support the top connection ring and the vacuum capsule mounting 3, additional insulating rings were required, parts 15, 16, and 17, Figure 9.

The design specification used for the 1000 V AC interrupter required 1/2" surface creepage and a 1/4" gap. This resulted in considerable less insulation material. Therefore, in the AC unit the vacuum capsule with radiators is positioned in the enclosing shell by three insulators at the bottom and three at the center of the shell. The insulators, part 19, Figure 8 , are equally spaced around the inside circumference of the shell. The connection ring, part 10, is positioned by two additional insulation rings, parts 17 and 18 of Figure 8.

4. Ion Pump

From the data obtained during the material outgassing test reported in Section IIIA of the second quarterly report, it was decided that a continuously operating vacuum pump would be required to maintain the pressure in the vacuum capsule near 1×10^{-6} Torr in the high ambient temperature (1000^{o}F). It was also concluded that a 0.5 liter per second ion pump would have the required capacity to hold this pressure level at the operating temperature.

The optimum operating temperature for the ion pump is 200^{o}C. This will require that the pump be cooled during all tests involving high temperature environment. For this purpose a forced air cooling system has been designed that will protect the ion pump magnet and electrical connection. Refer to part 2 of Figures 8 and 9 . The cool supply of air will be pumped in through the inner tube flowing over the electrical cable and pump body. The return for the air will be through the space between the magnet and the outside of the enclosure.

IV. OPERATING MECHANISM

The vacuum interrupter is moved by a mechanism, or actuator. This part of the device is mounted above the interrupter and on the same center line. This section of the report covers the work which has been done in arriving at the final design and completing all the detail drawings.

A. Actuator Design and Details

1. Over-all Arrangement

The major components of the actuator design shown in outline form, Figure 11 and in detail, Figure 12 , are:

- Closing Solenoid
- Diaphragms
- Flexural Pivots
- Actuator Linkage
- Latch and Trip Mechanism

The moving contact in the vacuum interrupter is operated by the solenoid which travels 3/8" to impart a 1/4" movement of the contact and a 1/8" compression of a contact pressure spring. Two diaphragms support the solenoid, and a linkage locks the interrupter closed.

B. Components

The closing solenoid, parts 2, 10, 19, and 26 of Figure 12 is similar to the conceptual design solenoid shown in the Phase I report. Minor changes were made during detailing to obtain a device to meet the mechanical environment for launch conditions and to provide the required operating force. The calculations and design dimensions, of the solenoid have been based on the use of materials suitable for the 540°C ambient. However some of the materials used in these samples (such as the coils) will not meet the full high temperature requirements.

2. Diaphragms

The diaphragms were the most difficult components to design to meet the mechanical requirements of the launch conditions.

First, several designs with long flexural paths made of different materials were vibration tested in a fixture designed to simulate conditions of the final device. The best material tested was A286 stainless steel. The last diaphragms vibration tested, made of this material, developed small fractures in the long flexural paths, but did not rupture entirely. This occurred during the dwell test at the high resonant frequencies, 1200 and 1400 cps.

Then, a means was developed to damp out these resonant frequencies which consisted of clamping the diaphragm between .005" thick discs of mylar. This material would evaporate at the high temperature in the vacuum of space without damage to the equipment.

However, due to the success with the copper electrical diaphragms, this design was considered for the actuator diaphragms. Using .003" thick A286 stainless steel on hand, diaphragms were fabricated with a single convolution as shown in Figure 13. These diaphragms, however, were not stiff enough radially. New diaphragms made of .0047" material developed small fractures in the slots at the edge of the center clamping disc. The radial sections of the diaphragms did not rupture and the diaphragms were still operable. This fracturing was then overcome by clamping the diaphragm between discs made of .0047" A-286 steel with the diameter of the disc .010" larger than the diameter of center clamping disc. These thin discs act as leaf springs and reduce the concentration of stress in this area. Vibration test data is included in the appendix.

3. Flexural Pivots

The environment in which the flexural pivot will be operated was re-examined to determine the possibility of using standard flexurals in the Phase II testing. High temperature coils will not be designed for the closing and trip solenoids of the AC breaker and DC contactor in this phase of the program. It follows, therefore, that the AC breaker and DC contactor cannot be operated during the heat run, high potential test, and 1,000-hour endurance run. Thus, the flexural is only required to support the actuator parts in the closed position at high temperature. During the interruption tests the breaker and switch will also be operated by solenoids with low temperature coils operating near room temperature, without the actuator latching toggle.

In view of these limitations, a flexural with high strength at high (1000°F) temperature is not required now, but would be considered in the next phase of the program. Standard flexurals which will have adequate strength for the static loads at high temperature have therefore been selected. Several were ordered for load testing purposes. They are available from stock. The standard flexural is brazed at 1600°F.

A standard flexural subjected to 100 lbs axial load for 2 hours at 1000°F was not damaged. Test and investigation is continuing.

4. Actuator Linkage

The initial tubular linkage of the conceptual design was found to be excessively long in actual layouts and has been replaced by the actuator linkage shown in Figure 11. The top of the linkage is shown in the open and closed positions of the vacuum interrupter in Figure 14 . The long members at the outer edges of the linkage are under stress when the device is closed. This stress is transferred to the center member which exerts the force to hold the contacts closed. It should be noted that the linkage passes through the vertical or dead center position by one degree in the latched position.

5. Latch and Trip Mechanism

The latch and trip mechanism performs four functions:

- Provides a stop in the latched position.
- Latches the actuator in the closed position electromagnetically for launch.
- Latches the actuator closed during normal operation using a permanent magnet.
- Performs the trip function by an electromagnet.

The details of this mechanism are shown in Figure 14 .

The stop buttons are made of tungsten to prevent welding and are adjusted to provide the one degree of travel past the center line of the device.

The latching electromagnet is intended for use during launch and during the tests simulating the mechanical launch environment. This device will not be used during normal operation in space. The electromagnet is designed to operate from a 12 volt DC source. 2.34 watts are dissipated at 25°C and the initial temperature rise rate is 125°C in 45 minutes. The holding force developed by the magnet is 42 lbs and is applied approximately one inch from the top of the actuator.

The permanent magnet latch is located 2 3/4 inches above the center of the flexural pivot and exerts a force of 6 lbs in the latched position. The magnet is positioned to maintain a gap of .032 inches between the magnet pole pieces and the armature on the actuator toggle. When the toggle is on dead center vertically the magnet will exert an attracting force of approximately 2 3/4 lbs to pull the toggle over center to the latched position.

The trip solenoid is designed to have an initial repelling force of 6 lbs and is located 6 1/4 inches above the center of the flexural pivot. The inch-pound torque of the trip solenoid is more than twice that of the permanent magnet latch. The trip solenoid is also designed to operate from a 12 volt DC source. At room temperature the two coils of the trip solenoid require 200 watts for operation and the temperature rate of rise for the coils is $4^{o}C$ per sec. At $150^{o}C$ the coils consume 140 watts and have a rate of temperature rise of $2.7^{o}C$ per second.

V. TEST PLANS AND FACILITIES

In accordance with the Contract, a wide range of electrical and mechanical tests are being planned for the sample vacuum breakers and contactors.

Test equipment is being checked out, and Test Specifications are being prepared. Some details on this work will be covered in this section of the report.

A. Electrical

A capacitor discharge type of test, similar to those performed in Phase I, is planned for both the AC Circuit Breaker and DC Engine Contactor. However, a much larger (135,000 joule) capacitor bank will be used this time. Adequate equipment is available in the discharge test control room for recording all data.

A problem area exists in obtaining a low circuit decay rate for the AC test. Data included in the Second Quarterly Report showed that with a circuit Q of 100 the decrease in current and voltage would be 25 to 27% in 4.5 to 5 milliseconds. A preliminary calculation of the final breaker design, using average spring forces, indicates that the contacts will open .020 inch in 6.5 milliseconds. This time is based on the contacts parting 5.3 milliseconds after the collapse of the closing solenoid magnetic field.

To maintain the circuit values, an alternate approach of supplying power from a fixed source, equal to the decrement loss during the test, is now under investigation.

The interruption tests will be made with the interrupter in a special inert gas oven (atmospheric pressure) and the operating solenoid outside the oven in a lower temperature. The coil for this test has been designed, and will use 314 turns of # 15 copper wire with ML (glass-polyester) insulation. At the expected operating temperature of 150°C, the coil will draw 13.2 A at 12 V, for a total of

4150 amp turns and 158 watts.

B. Mechanical

The facilities for vibration and shock testing are available in the Research and Development Center. The vibration facility has already been used in component development tests, as explained in the mechanism design section of this report. The fixtures for testing the switchgear devices have not yet been designed, but this work is planned for the near future.

Additional mechanical tests using a high impact shock machine, a centrifuge for acceleration, and an acoustic sound chamber are being planned. Detail test specifications are in preparation.

C. Heat Run and Endurance

The special oven that will provide the $1000^{\circ}F$ environment in the high vacuum chamber is now being assembled. After assembly, it will be annealed and then stored in inert gas until placed in the test chamber.

Final electrical circuitry is being detailed and authorizations will be issued in October to start the installation work. The special heat run transformer has been tested, and problems encountered in maintaining a low enough inductance in the connections at the high frequency (up to 3200 cps) require further study. The transformer must also be redesigned to provide adequate output at the high frequency.

Test Procedures or Specifications for the heat run and high voltage leakage tests have been written. Copies of typical Specifications are included in the Appendix.

VI. APPENDIX

This Appendix includes several exhibits concerning the testing activity that is underway for the Switchgear Program.

The information in this section of the report is the following:

1) Test Specification # R&DC-TS1.

   Vibration Test of Sample Diaphragms.

2) Test Result # R&DC-TR1.

   Vibration Test of Sample Diaphragms.

3) Test Specification # SPPS-TS1.

   Heat Run-Test on AC Circuit Breaker.

4) Test Specification # SPPS-TS2.

   Heat Run Test on DC Contactor.

VII. SCHEDULE

The detail drawings of all parts of the actuator and vacuum interrupters, with the exception of the vacuum capsule, have been sent out to vendors to obtain quotations on the parts. Both the Research and Development Center and the Space Power and Propulsion Section are participating in obtaining the quotations. Quality Control will be maintained in accordance with the Procedure Manual developed as part of this Program.

The parts for the vacuum capsule will be fabricated in the R&DC shop because control of the machining methods especially on the molybdenum and Rodar is important. Vacuum processing, assembly, evacuating, and seal off of the capsule will be done either at the Laboratory Operation of the Switchgear Department in Philadelphia, or at SPPS in Evendale.

All material has been ordered for the actuators and vacuum interrupters, and the material for the actuators has been received. All material will be furnished to vendors, who will manufacture the various parts. This procedure is being followed because all of the material must be certified to conform to specifications. The vendors will be instructed not to make material substitutions.

The overall schedule is now being reviewed in detail, in the light of delays in completing detail drawings, obtaining quotes on fabrication, and the longer than expected fabricating times that have been promised. It now appears that the first complete breaker cannot be assembled before December. However, the additional units should be available early in 1966 so the test program can proceed with little delay and the important interruption tests are expected to be completed about the end of March, 1966.

TEST RESULTS

NO. R&DC - T.R. 1

PROGRAM

Electrical Switchgear for Nuclear Electrical Systems

TYPE OF TEST

VIBRATION TEST - Diaphragm Evaluation Test

CONTRACT NO. NAS 3667

LOCATION OF TEST

G.E. Company, Schenectady, New York, Bldg. #37 - R&DC

TEST SPEC. REF. (NO. & DATE) R&DC TS-1 8/16/65

I. Diaphragm Part 8 of PL 587E474, Dwg. 561B497. (Made of .0047" Stainless Steel).

II. All measuring instruments and oscilloscope are included in the vibration equipment console.

III. A. Vibration excitation applied radially to diaphragm.

The frequency ranges were scanned in accordance with IV. of the test specification R&DC - T.S.1. Resonances occurred at 161 and 254 cps. Five minutes dwell at each of these two frequencies did not damage the diaphragms.

B. Vibration excitation applied axially to diaphragm.

The frequency ranges were scanned in accordance with IV. of the test specification R&DC T.S. 1. Resonances occurred at 1198 and 1405 cps. Five minutes dwell at each of these two frequencies did not damage the diaphragms.

FORMAT	PREPARED BY	
I. Device Tested II. Reference to measuring instruments used - date last checked III. Results - Description - Tabulation of values	E. F. Travis SIGNATURE	8/16/65 DATE

SP 1146A

TEST SPECIFICATION	TEST SPEC. NO. R&DC - T.S. 1
PROGRAM Electrical Switchgear for Space Nuclear Electrical Systems	
TYPE OF TEST VIBRATION TEST - Diaphragm Evaluation Test	CONTRACT NO. NAS 3-6467
LOCATION OF TEST FACILITY (CITY, BLDG) G.E. Company, Schenectady, New York - Bldg. #37 - R&DC	APPROVED BY

I. Diaphragms Part 8 of PL 587E474, Dwg. 561B497. (Made of .0047" A236 Stainless Steel).

II. Two diaphragms should be mounted in Test Fixture # 1, Dwg. 454C795 with the convolutions facing outward. Four washers, Dwg. 115A518 should be mounted next to each diaphragm with one on each side of the diaphragm.

III. The test fixture should be bolted securely to the vibration head of the Model 91A Unholtz-Diky vibration equipment. This equipment consists of the vibration head and control console complete with frequency and amplitude controls.

IV. Scan the frequency range in 1 to 10 minutes with logarithmic sweep on each of three major axis at the inputs tabulated below. At each major resonance frequency sine wave excitation will be applied for 5 minutes at the levels specified below:

Frequency	Scan Level	Resonance Level
16 - 100 cps	6 "g"	3 "g"
100 - 180 cps	0.118: P/P	0.0059" P/P
180 - 2000 cps	19 "g"	9.5 "g"

FORMAT	PREPARED BY
I. Device to be tested II. General description of test III. Test facilities including description, reference & type IV. Detail test procedure	E. F. Travis (SIGNATURE) 8/16/65 (DATE)

SP 1145

TEST SPECIFICATION

TEST SPEC. NO.	Switchgear - T.S. 1
PROGRAM	Electrical Switchgear for Space Nuclear Electrical Systems
TYPE OF TEST	Heat Run - Design Evaluation Test
CONTRACT NO.	NAS 3-6467
LOCATION OF TEST FACILITY (CITY, BLDG)	G.E. Co., Evendale, Ohio - Bldg. # 700 - SPPS
APPROVED BY	

1) AC Vacuum Circuit Breakers rated 1 phase, 600 A, 2000 cps.
2) Place Breaker in an environment of 1000°F, 10^{-6} Torr (or lower) pressure, and measure temperature rise while carrying up to 600 A continuously until a steady state condition is observed. Record temperature of critical parts and current with 200, 400, and 600 A.
3) Units to be mounted in special oven Drawing # 941D621, and placed in high vacuum chamber designated CIV. Power for test current supplied by special high current transformer from Behlman high frequency electronic generator. Thermocouples to be Platinum-Platinum/Rhodium with automatic reading of values on Honeywell recorder along with current measurements.
4) Test Procedure
   A. Set-Up
      1) Attach thermocouples to show vital hot spots on accessible points of Breaker as shown on detail layout drawing.
         NOTE: A total of 18 thermocouples will be available for the AC Breakers. Use 8 on the actuator and 10 on the interrupter. All leads must be twisted while in high frequency field.
      2) Connect Breaker to a pair of high current feed-thrus, using co-axial copper bus except for last 6" which will be a special "heat limiting" #4 OFHC copper wire jumper. Also connect the floating shield of both breakers to 5A, 7.9 KV feed-thru conductors.
      3) Outside terminals of high current feed-thrus are to be connected to the high current transformer, permitting current adjustment and high voltage testing.
      4) Use C.T. built into high current transformer for current measurement.
   B. Heat Run
      1) Connect the Breaker power feed-thrus in series with the high current transformer. The primary of the transformer will be supplied by the Behlman variable frequency power unit, set at 2000 cps.
      2) Use transformer bushing C.T. to provide measuring current to a calibrated ammeter suitable for the frequency, and to a resistance for a voltage measurement which will be plotted on the automatic recorder with the DC current and all thermocouple values.
      3) Raise voltage (and current) in steps of 200A., holding each value until temperature is constant with the oven at 1000°F.
      4) At the conclusion of the Heat Run, make High Voltage Leakage test (Refer to Test Specification # Switchgear - T.S. 3).

Revised 8/30/65

FORMAT	PREPARED BY
I. Device to be tested II. General description of test III. Test facilities including description, reference & type IV. Detail test procedure	A. H. Powell (SIGNATURE) 7/28/65 (DATE)

TEST SPECIFICATION	TEST SPEC. NO. Switchgear T.S.2
PROGRAM: Electrical Switchgear for Space Nuclear Electrical Systems	
TYPE OF TEST: Heat Run - Design Evaluation Tests	CONTRACT NO. NAS 3-6467
LOCATION OF TEST FACILITY (CITY, BLDG): G.E. Co., Evendale, Ohio - Bldg. # 700 - SPPS	APPROVED BY: Later

1) One DC Vacuum Contactor rated single pole, 10A., 10KV.

2) Place Contactor in an environment of 1000^{o}F, 10^{-6} Torr (or lower) pressure, and measure temperature rise while carrying 10 amperes continuously.

3) Unit to be mounted in special oven Drawing # 941D621, and placed in high vacuum chamber designated C IV. Current for test supplied by DC rectifier power supply with AC input. Thermocouples to be Platinum-Platinum/Rhodium, with automatic reading of values, along with current measurement.

4) Test Procedures

   A) Set-Up

      1) Attach 6 thermocouples to measure the enclosing shell and mechanism temperature. No T/C's will be placed on live parts, as the rise with 10 amperes DC flowing should have minimum effect on the temperature, and overall temperature only will be monitored. The detail layout drawing will show the T/C locations.

      2) Connect the terminals to pairs of 5A., 1 KV feed-thru leads with # 12 copper conductors. Connect the external feed-thru terminals to the DC power supply, with provisions for current measurements.

      3) Attach a well insulated (25 KV) small (# 14) lead from the floating shield on the Contactor to the 25 KV feed-thru, for use in the Hi-Potential Leakage Test.

   B) Heat Run

      1) Connect the contactor to the 10 A DC power supply, at the feed-thrus. Use an ammeter to measure the current, and a series resistor to provide a voltage measurement which will be recorded on the automatic equipment along with all T/C values.

      2) Raise current to 10 amperes, and maintain this value during the heat run test.

      3) At the conclusion of the Heat Run, make High Voltage leakage test (refer to Test Specification # Switchgear - T.S. 4).

FORMAT	PREPARED BY
I. Device to be tested II. General description of test III. Test facilities including description, reference & type IV. Detail test procedure	A. H. Powell (SIGNATURE) 7/29/65 (DATE)

TABLE 1

CONTACT RESISTANCE WITH CHANGE OF TEMPERATURE IN TEST CAPSULE

Current Amps	Contact Volts	Micro-Ohms	Pressure Torr	Temperature ^oF T_2	T_3	T_4	T_5	T_6	T_7
100	.005	50.0	$3x10^{-8}$	155	-	-	-	330	185
195	.011	56.1	$4x10^{-6}$	420	480	440	180	335	430
200	.014	70.0	$7x10^{-7}$	560	570	510	210	505	580
400	.033	82.5	$8x10^{-7}$	860	1080	1070	340	630	830
450	.037	82.2	$1x10^{-6}$	915	1210	1240	425	550	865
495	.041	82.8	$1x10^{-6}$	920	1300	1360	450	540	855
555	.047	84.6	$3x10^{-6}$	980	1420	1500	505	550	900
600	.055	91.6	$8x10^{-6}$	1020	1520	1610	540	555	920
600	.054	90.0	$5x10^{-6}$	1015	1525	1610	550	560	930

Thermocouple Location

T_2 - Top Stud
T_3 - Top Contact
T_4 - Bottom Contact
T_5 - Bottom Stud
T_6 - Oven Air
T_7 - Top Bolt Flange

Note: The temperature in the table are stabilized values at each contact current level. Current is 60 cps.

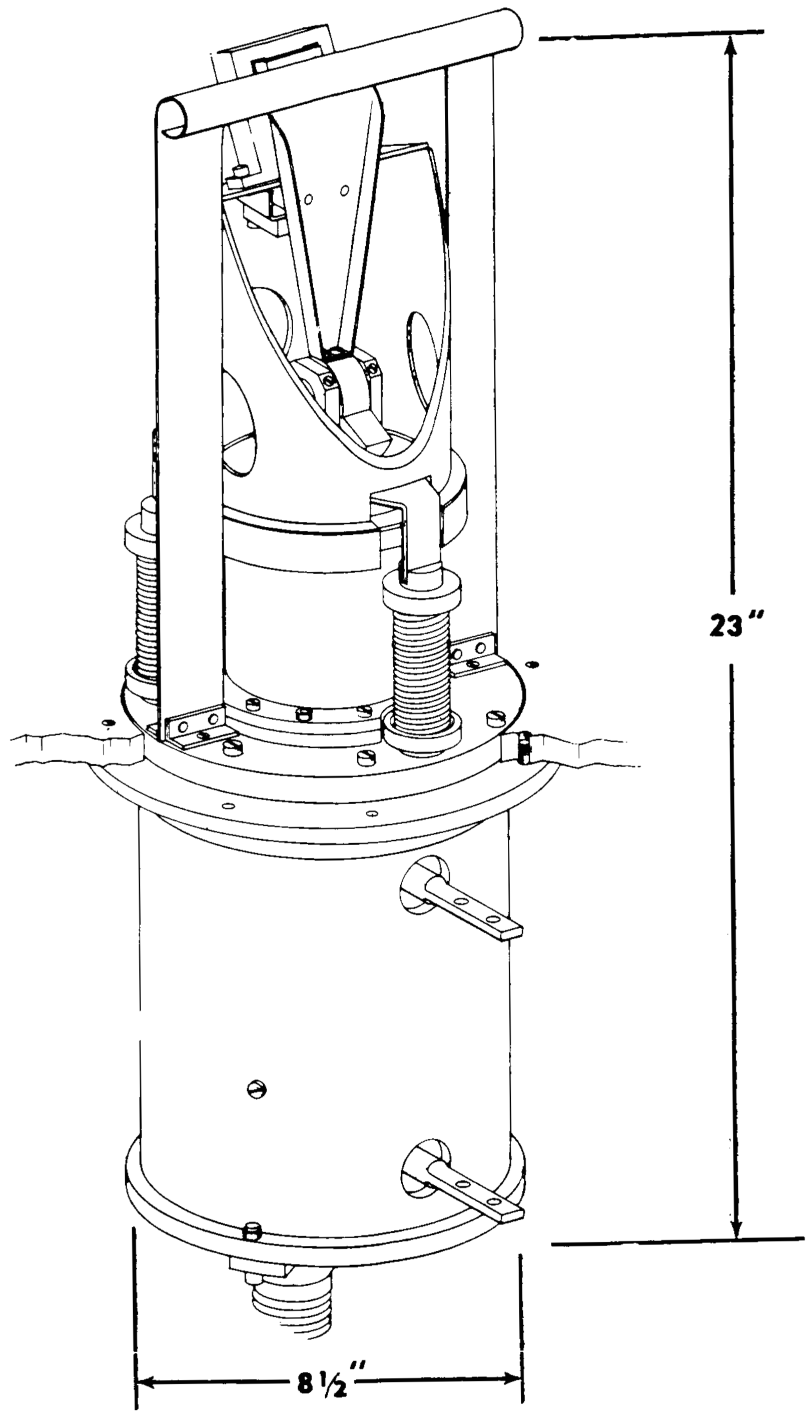

Figure 1: AC Vacuum Circuit Breaker Rated 600A, 1000V, 2000 cps.

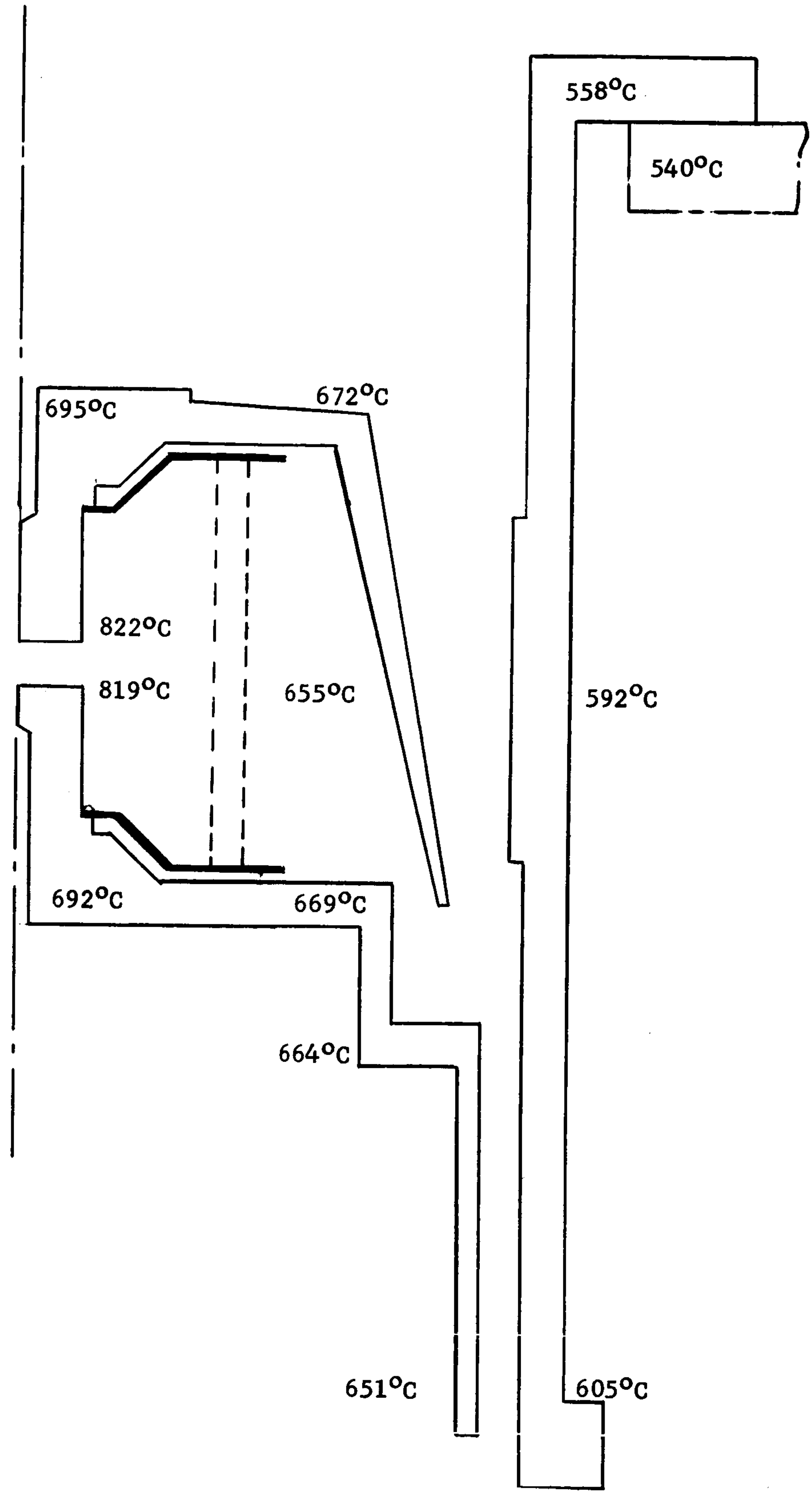

Figure 2: Calculated Contact and Heat Transfer Surface Temperatures for AC Vacuum Circuit Breaker.

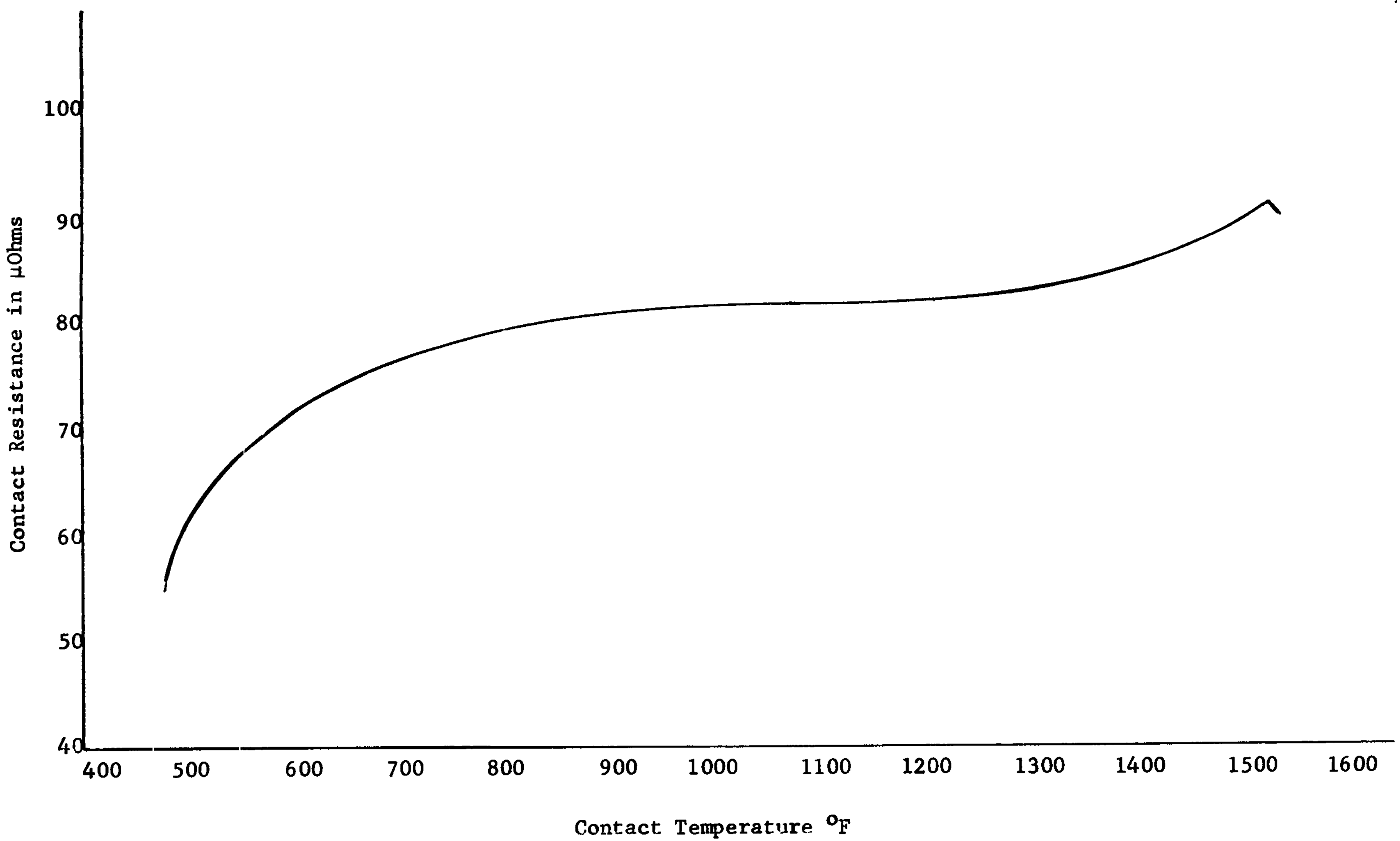

Figure 3: Relationship of Contact Resistance to Temperature of Sample Molybdenum Contacts.

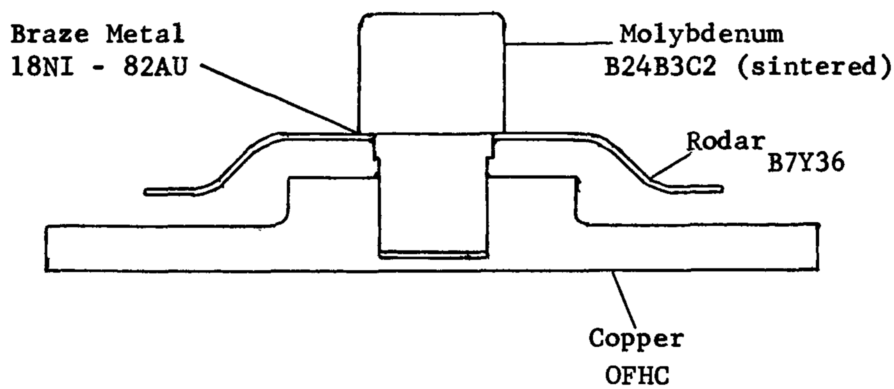

Figure 4: Sketch of Brazed Vacuum Capsule Contact Assembly.

STEADY STATE TEMPERATURE OF BRAZED SAMPLE SWITCH END

	Thermocouple (1) Number	Temperature °F
With Complete Shielding		
Run #1	1	1570
	2	1570
	3	1370
	4	1470
	5	1430
Run #2	1	1540
	2	1570
	3	1420
	4	1450
	5	1420
Without Top Shield		
Run #1	1	1470
	2	1560
	3	1120
	4	1300
	5	1200

(1) Thermocouple Location

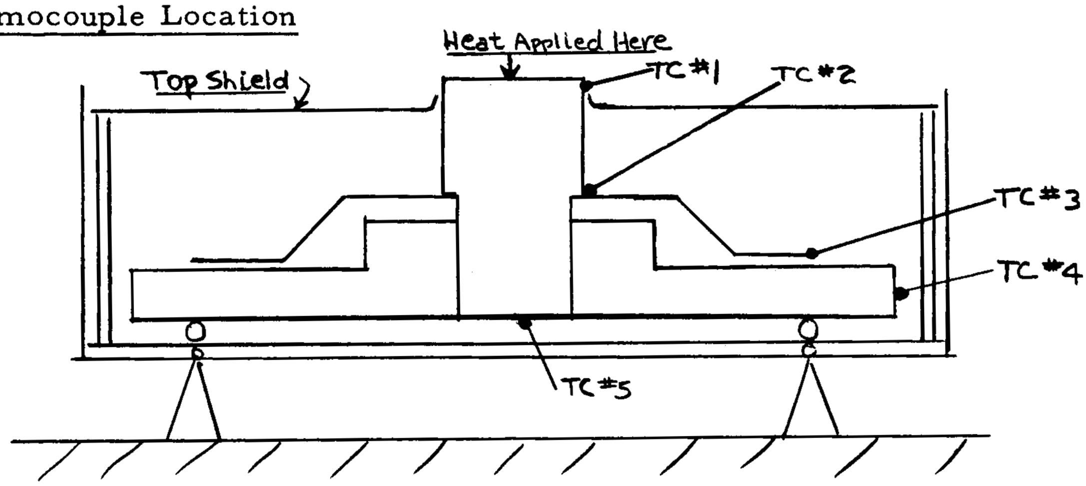

Figure 5: Brazed Sample # 1 in Set-Up for Heat Run and Resulting Temperatures.

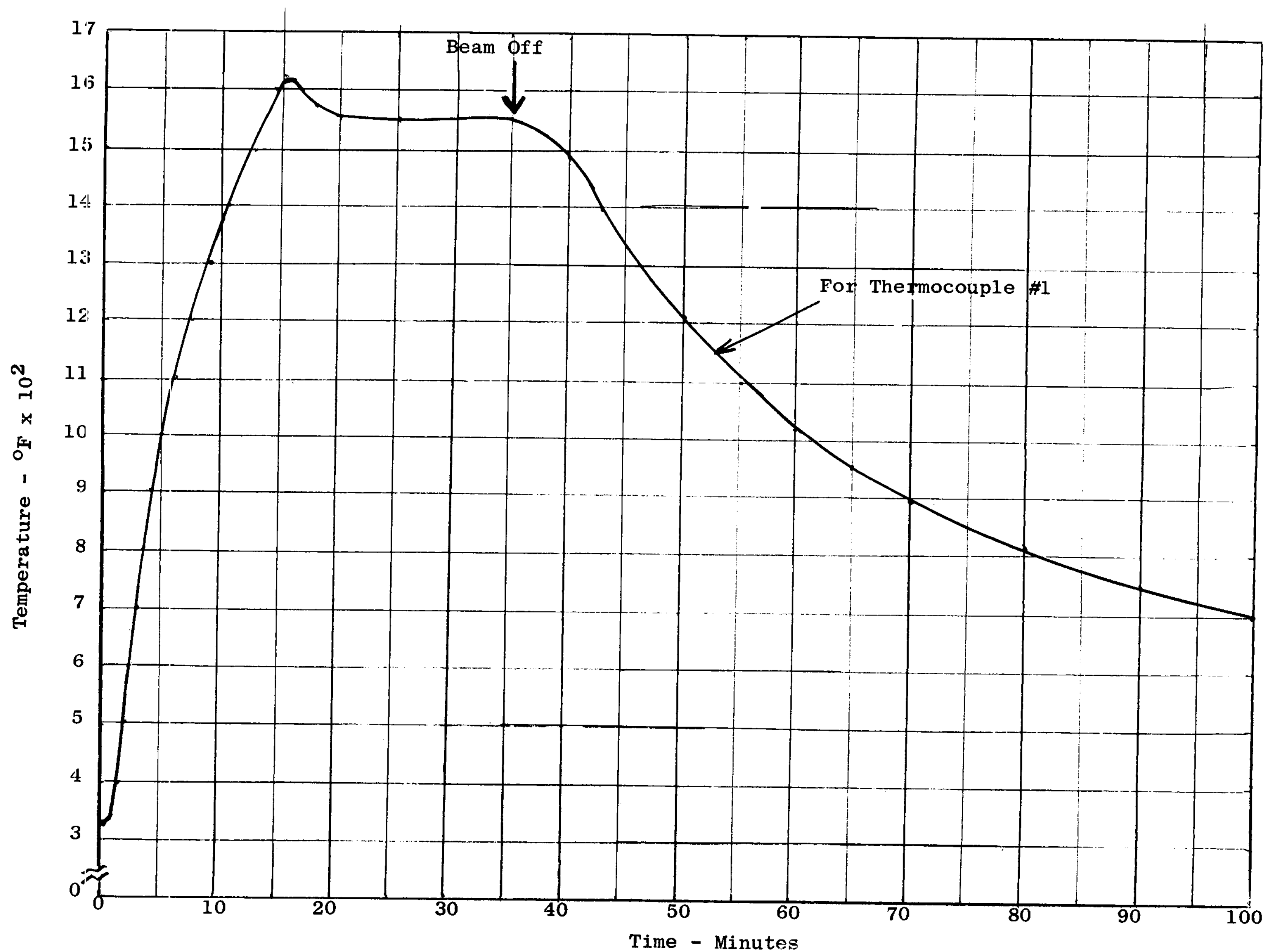

Figure 6: Temperature of Contact in Brazed Sample # 1 During Heat Run with Shield in Place.

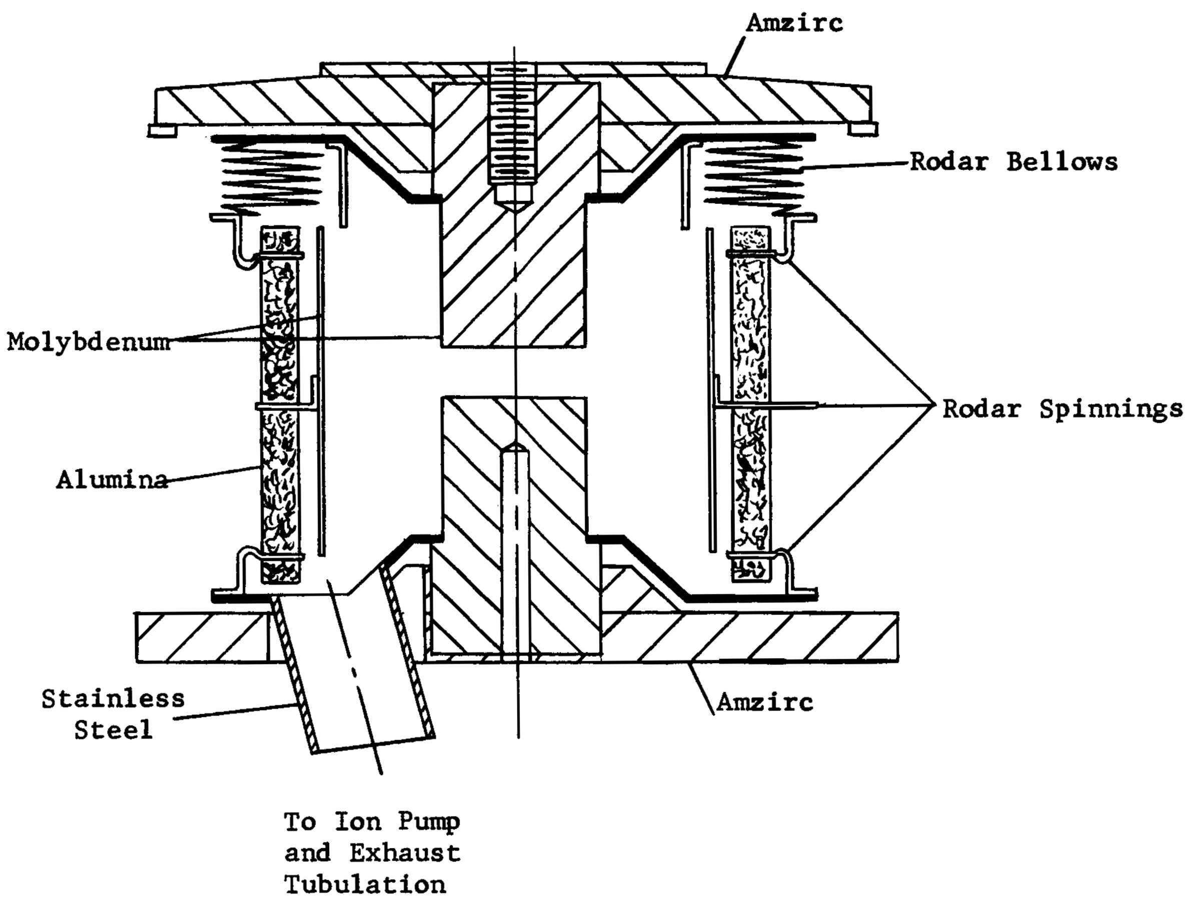

Figure 7: Sketch of Vacuum Capsule for Both AC Breaker and DC Contactor.

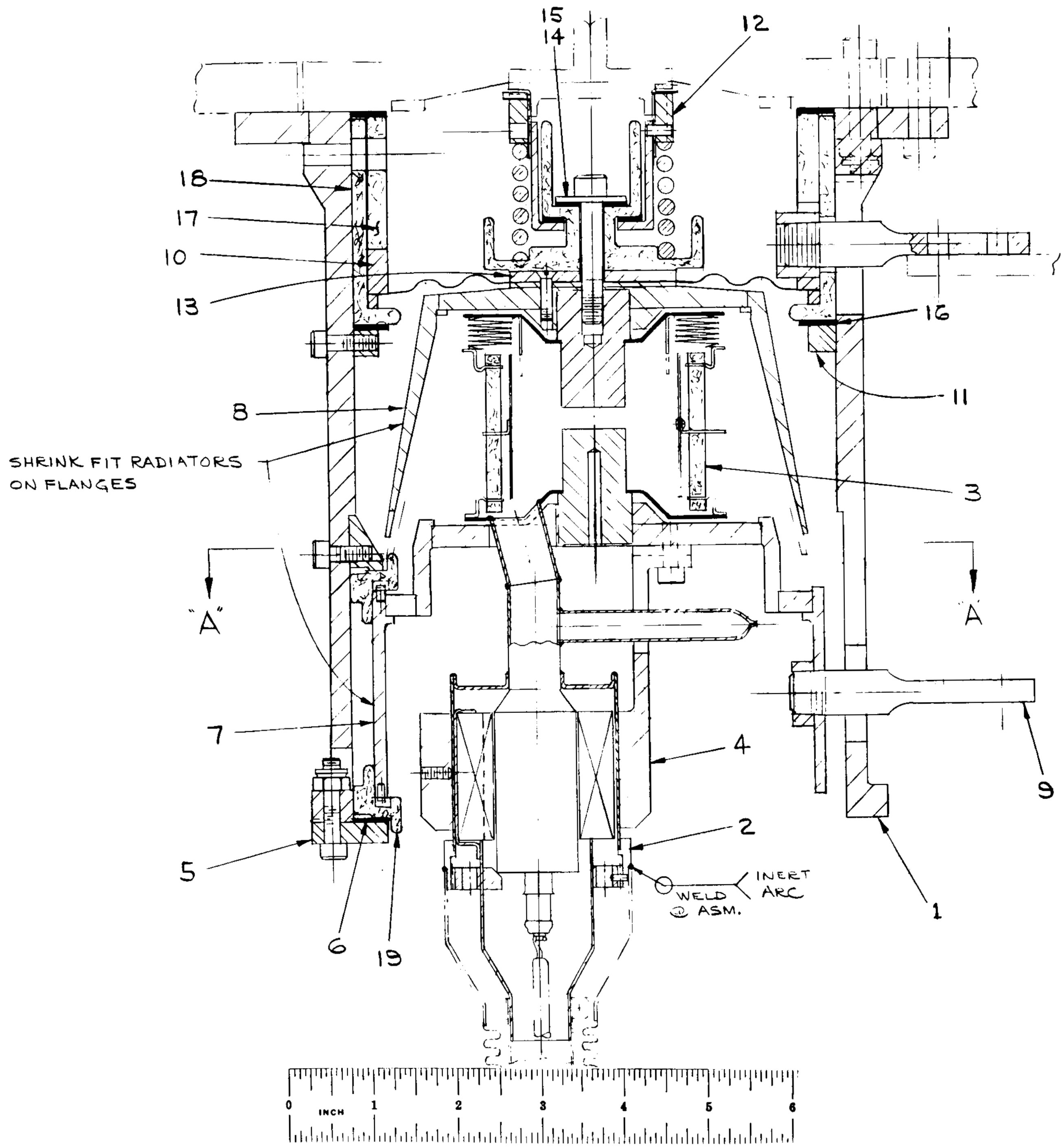

Figure 8: Layout of Vacuum Interrupter for AC Circuit Breaker.

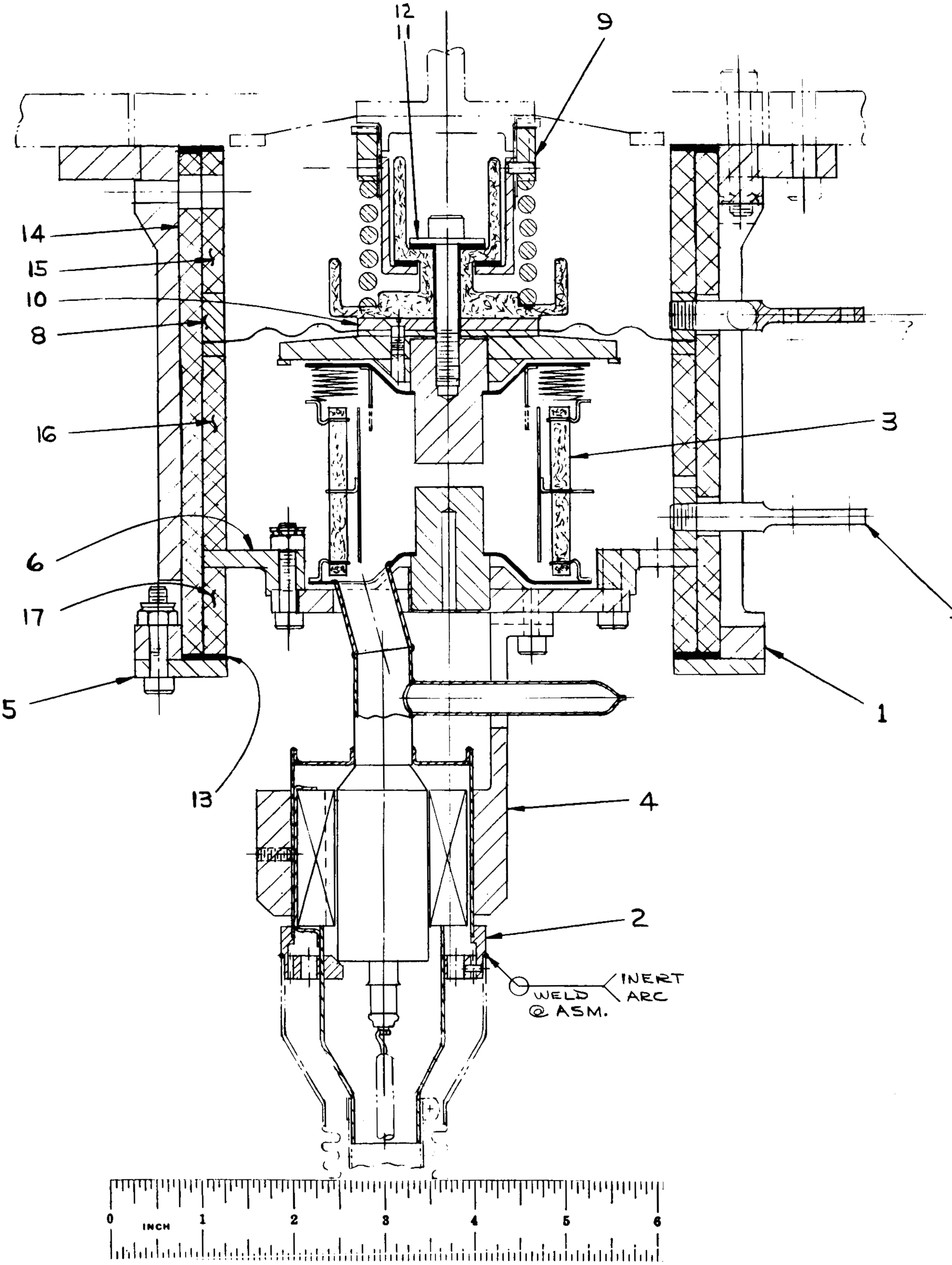

Figure 9: Layout of Vacuum Interrupter for DC Contactor.

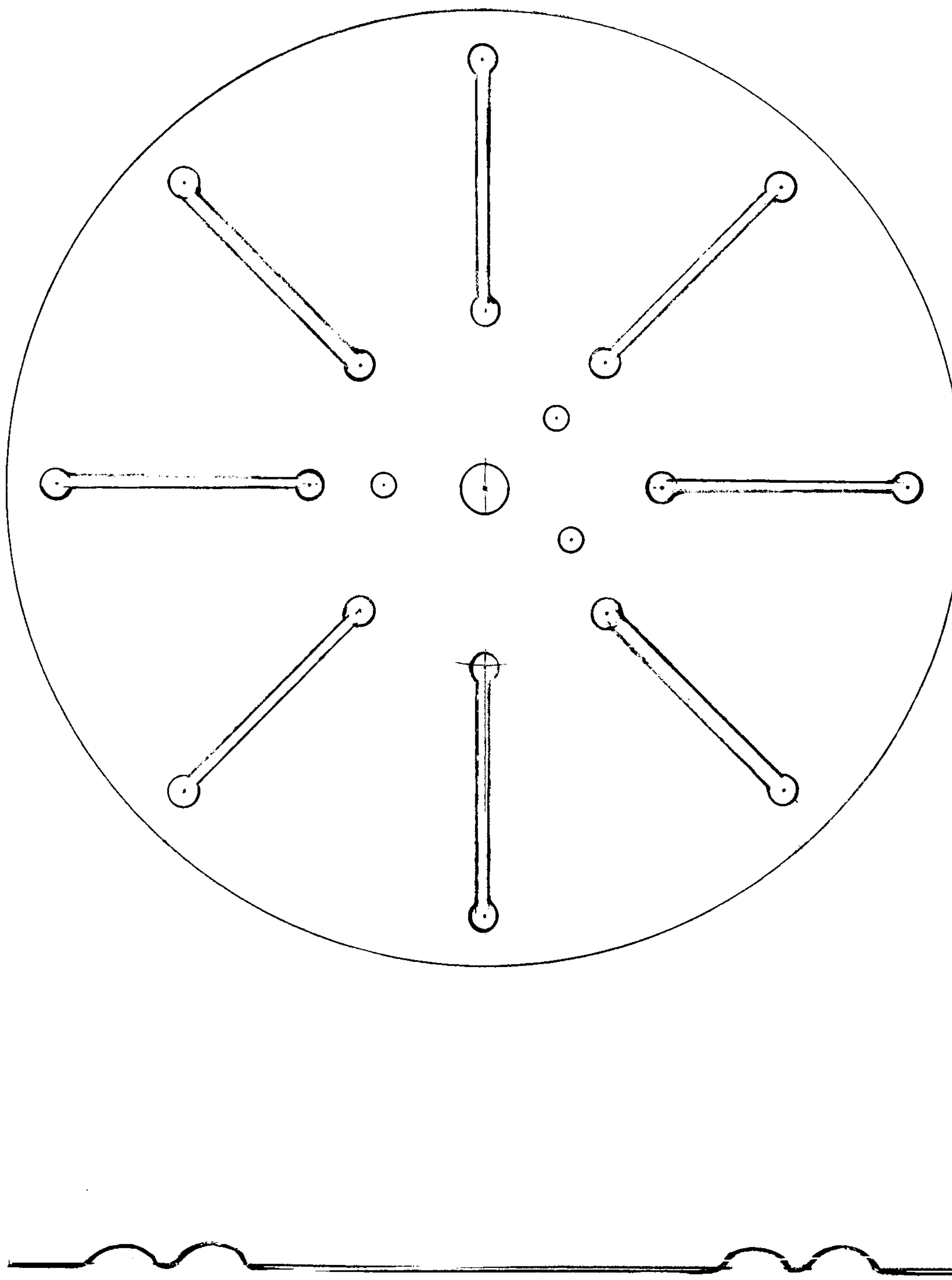

Figure 10: Flexible Electric Conductor (Diaphram) for Moving Contact of Capsule.

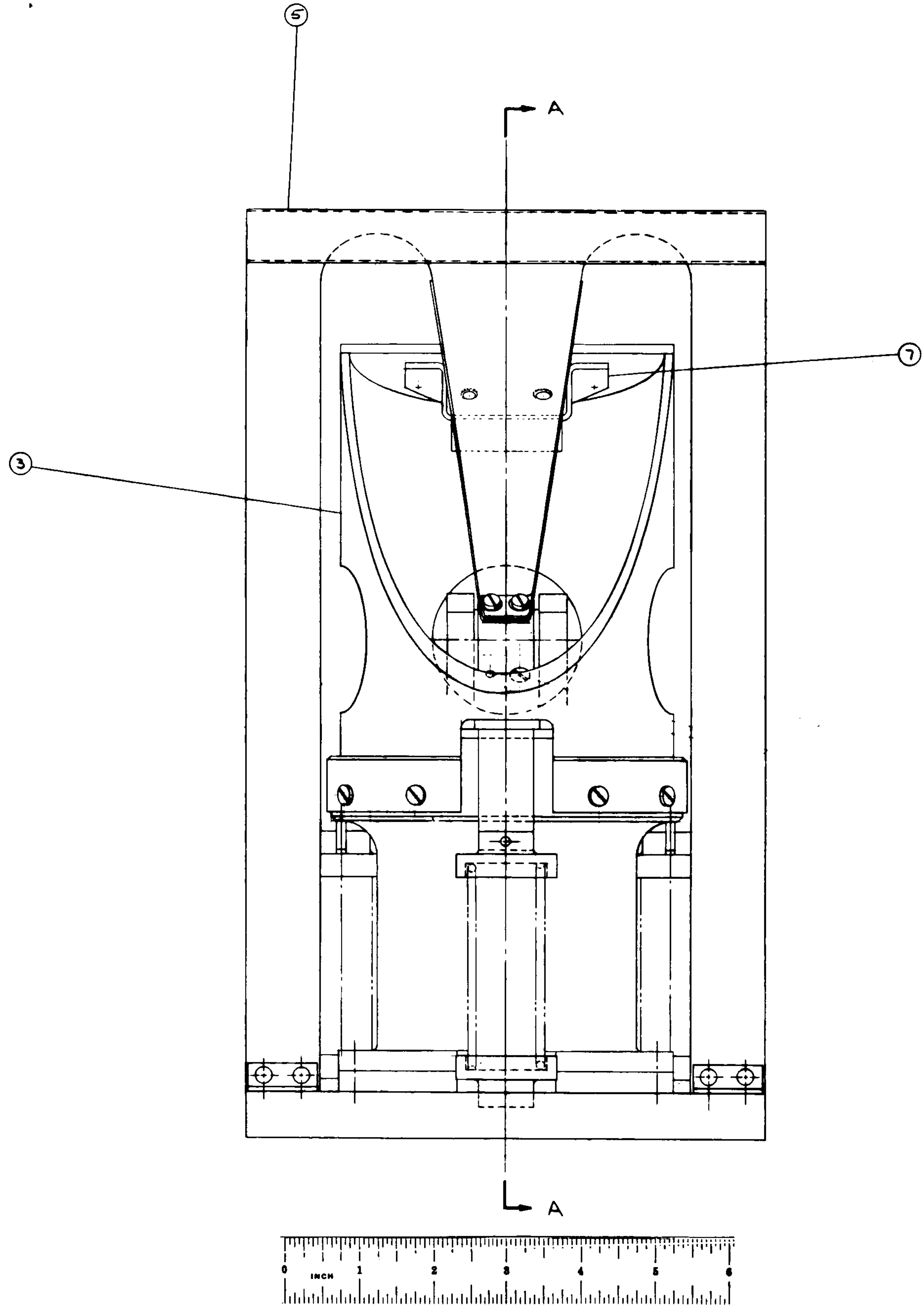

Figure 11: Overall Outline of Operating Mechanism (Actuator).

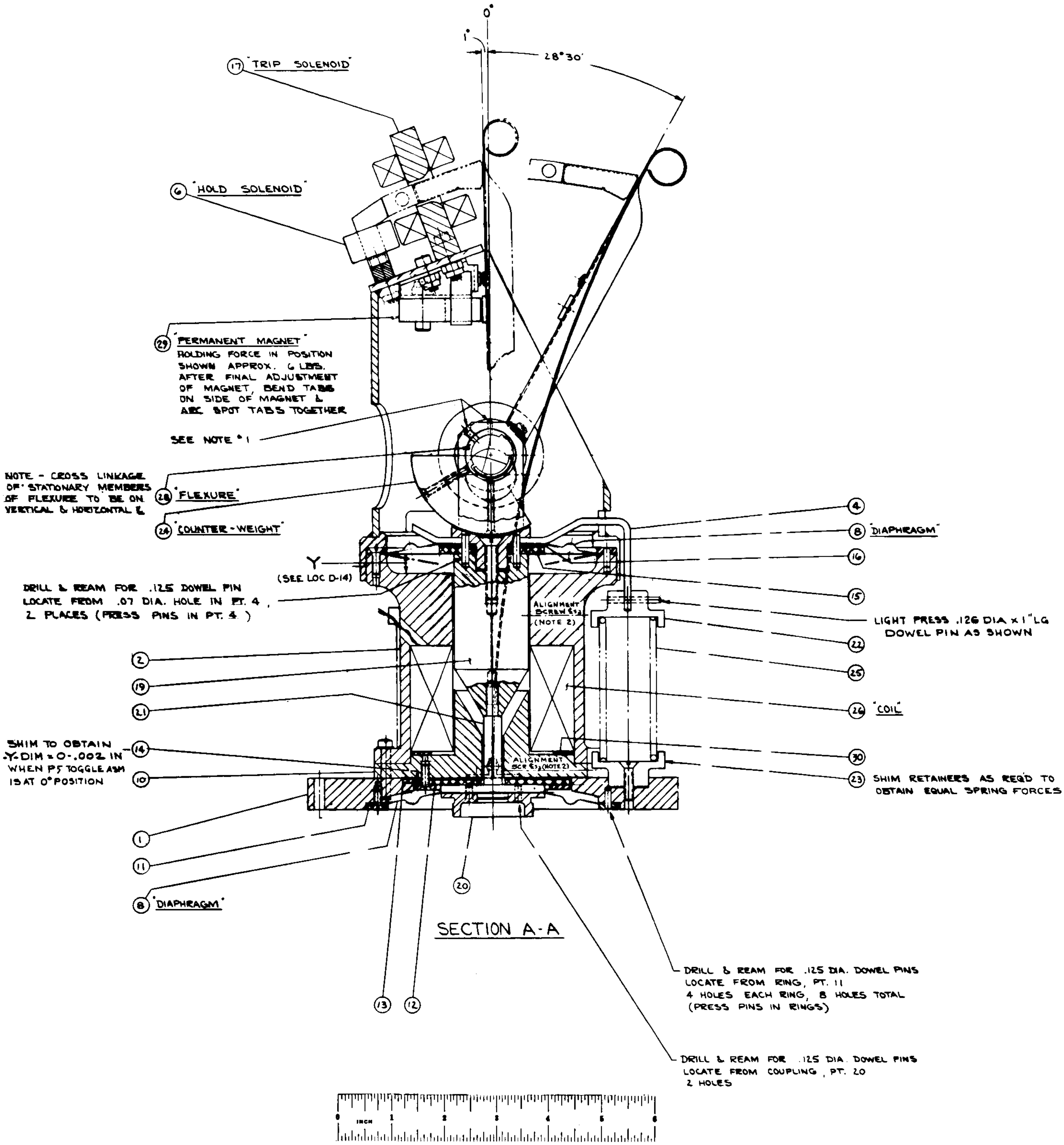

Figure 12: Layout in Detail of Operating Mechanism (Actuator).

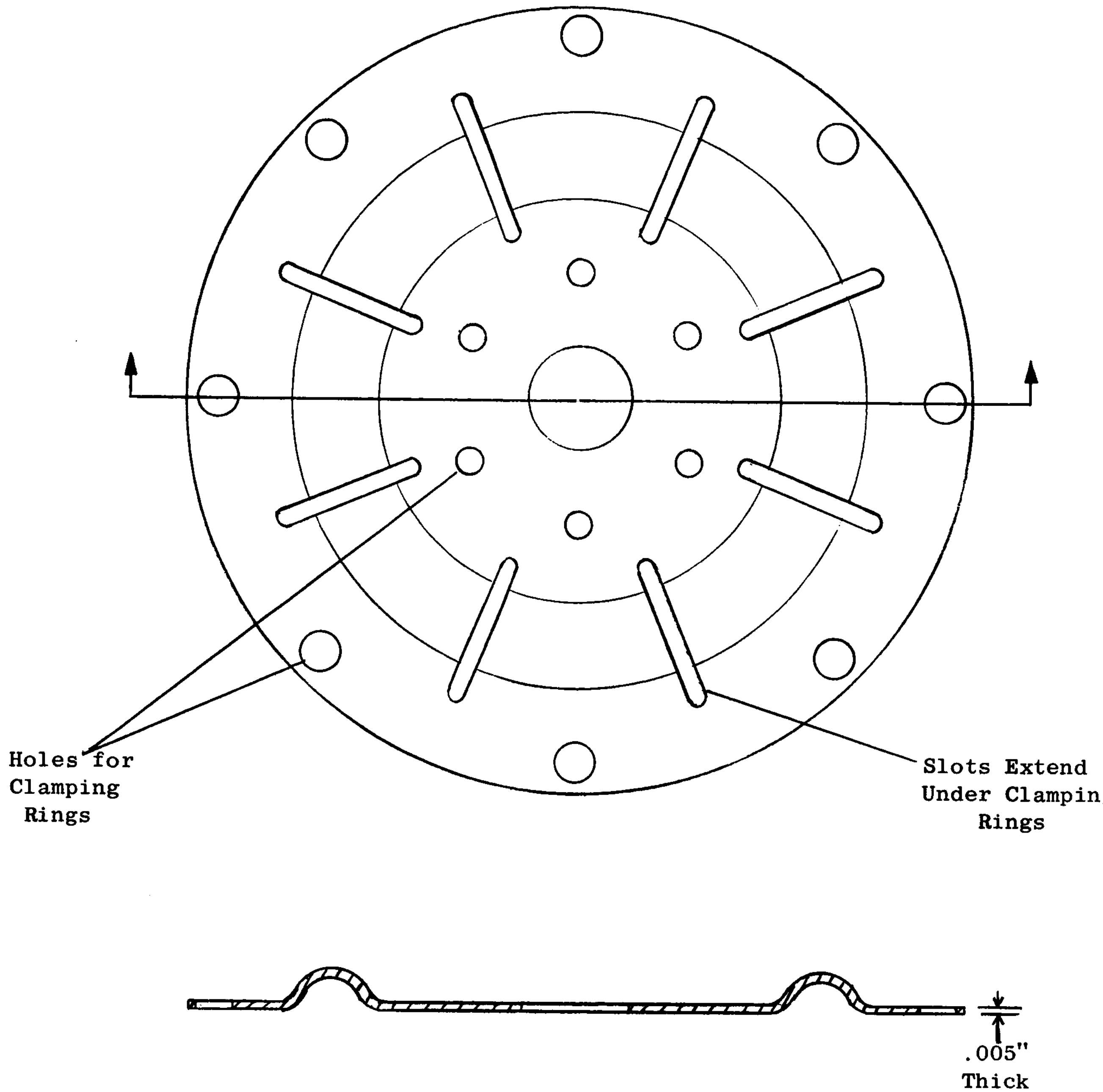

Figure 13: Arrangement of One of the Diaphragms Used to Support the Actuator Solenoid Plunger.

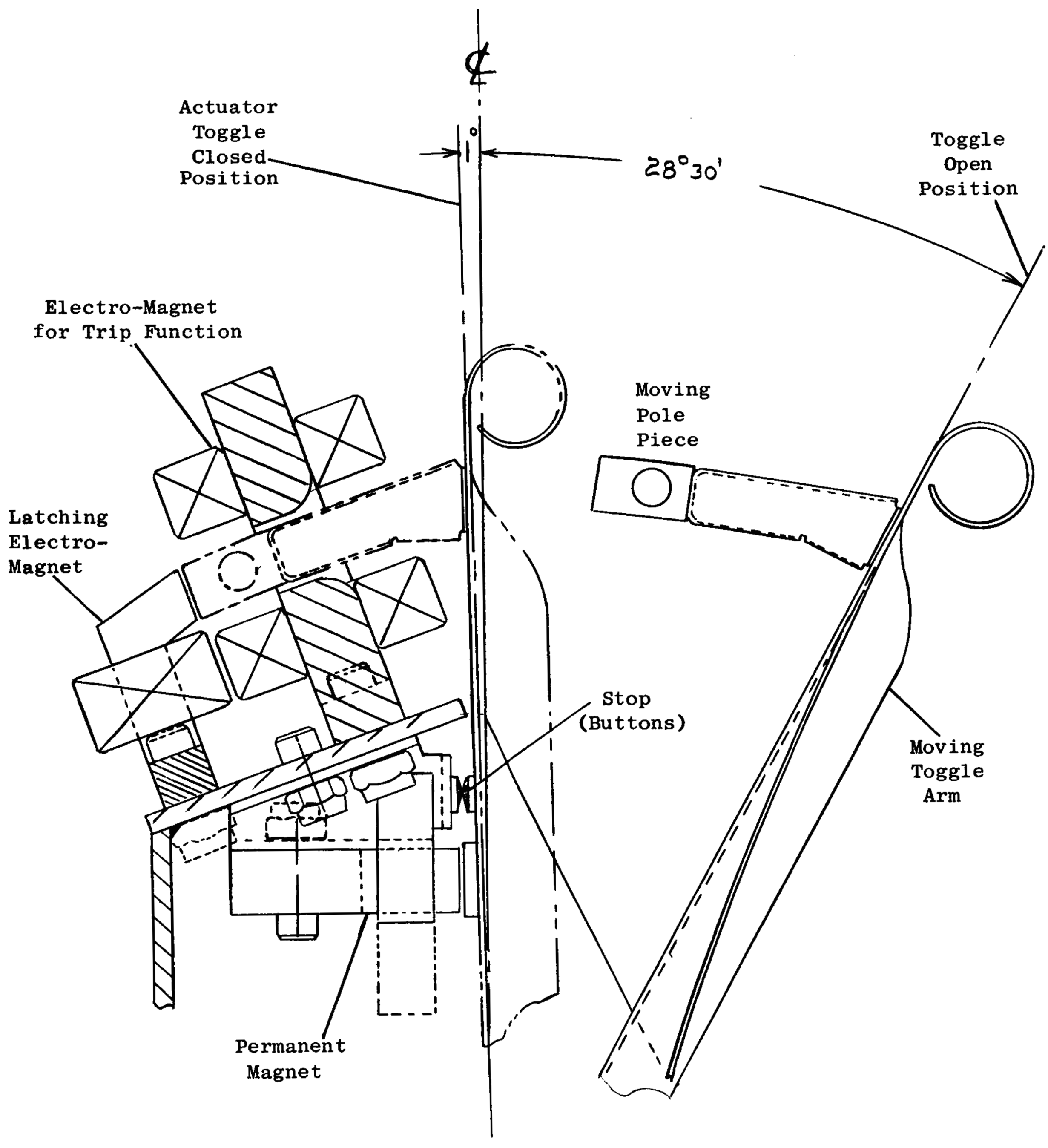

Figure 14: Actuator, with Latch and Trip Mechanism, Shown in Closed and Open Position.

DISTRIBUTION

TECHNICAL REPORT DISTRIBUTION LIST

Quarterly and Final

NAS3-6467

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 35th Street
Phoenix, Arizona
Attn: Librarian, John Dannen

Advanced Research Project Agency
The Pentagon
Washington 25, D.C.
Attn: John Huth

Allis-Chalmers
Thermal Power Department
P.O. Box 512
Milwaukee 1, Wisconsin

Air Force Institute of Technology
Wright-Patterson Air Force Base, Ohio
Attn: Commandant

Air Technical Intelligence Center
Wright-Patterson Air Force Base, Ohio
Attn: Commander

Air University Library
Maxwell Air Force Base, Alabama
Attn: Director

Commander, AFDC
Andrews Air Force Base
Washington 25, D.C.
Attn: RDTAPS, Capt. W. G. Alexander

U.S. Atomic Energy Commission
Germantown, Maryland
Attn: Lt. Col. G. H. Anderson

Avco
Wilmington, Massachusetts
Attn: Librarian

TECHNICAL REPORT DISTRIBUTION LIST CONTINUED

Convair-Astronautics
5001 Kearny Villa Road
San Diego 11, California
Attn: Krafft A. Ehricks

General Electric Company
Missile & Space Vehicle Dept.
3198 Chestnut Street
Philadelphia 4, Pennsylvania
Attn: Edward Ray

Dr. James Hadley
Head, Reactor Division
Lawrence Radiation Laboratory
Livermore, California

Hughes Aircraft Company
Engineering Division
Culver City, California
Attn: Tom B. Carvey, Jr.

Institute for Defense Analysis
Universal Building
2825 Connecticut Avenue, N.W.
Washington, D.C.
Attn: N. W. Snyder

Lockheed Missile & Space Division
Sunnyvale, California
Attn: Charles Burrell

Lockheed Aircraft Corporation
Missile Systems Division
Palo Alto, California
Attn: Hal H. Greenfield

National Aeronautics & Space Administration
Ames Research Center
Moffett Field, California
Attn: Library

National Aeronautics & Space Administration
Goddard Space Flight Center
Greenbelt, Maryland
Attn: Milton Schach

National Aeronautics & Space Administration
Jet Propulsion Laboratories
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California
Attn: D. R. Bartz (2 copies)

National Aeronautics & Space Administration
Langley Research Center
Langley Field, Virginia
Attn: Library

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: C. S. Corcoran, MS 500-201

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: B. Lubarsky, MS 500-201

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: George Mandel, Library

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: R. L. Cummings, MS 500-201

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: H. A. Shumaker, MS 500-201

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: E. A. Koutnik, MS 500-201 (5 copies)

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: I. I. Pinkel, MS 5-3

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: L. Rosenblum, MS 106-1

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: R. F. Mather, MS 500-309

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: John E. Dilley, MS 500-309

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: John J. Weber, MS 3-16

National Aeronautics & Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: Report Control Office, MS 5-5

National Aeronautics & Space Administration
Marshall Space Flight Center
Huntsville, Alabama
Attn: Ernest Stuhlinger

TECHNICAL REPORT DISTRIBUTION LIST CONTINUED

National Aeronautics & Space Administration
Marshall Space Flight Center
Huntsville, Alabama
Attn: Russell H. Shelton

National Aeronautics & Space Administration
1520 H Street, N.W.
Washington 25, D.C.
Attn: James J. Lynch

National Aeronautics & Space Administration
Scientific & Technical Information Facility
P.O. Box 5700
Bethesda 14, Maryland
Attn: NASA Representative

Naval Research Laboratory, Code 1572
Washington 25, D.C.
Attn: Mrs. Kathrine H. Case

Electro-Optical Systems, Inc.
300 No. Halstead Street
Pasadena, California
Attn: Library